FINAL REPORT ON COMBINING PHOTOGRAMMETRY AND 3D LASER SCANNING

FOR THE 3D DATA ACQUISITION AND MODELLING SERVICES PROJECT

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Abstract

The results of a technology demonstration study are presented for the Defence Research & Development Canada (DRDC) Toronto's Human Modelling Group. This report describes a method and system for integrating laser scanner and digital photogrammetry data. It proposes and demonstrates an integrated solution using a Cyrax laser scanner, Olympus 5050 Digital Camera, PhotoModeler Software, and Innovmetric Polyworks software.

The proposed system enables digital photogrammetry to be used to: augment and back up laser scanning coverage, add detailed local coverage to a larger global model, provide semi-automated photo texturing of three-dimensional (3D) models (reducing polygon counts in some cases), reduce the required laser scanning grid size for some objects, and extract features or dimensions from previously archived images.

This study found that cm level accuracy can be obtained from photogrammetry of large objects (as shown in the pilot project by measuring two sides of the DRDC Toronto building). Recommendations are made for implementing this technology, especially by replacing existing digital photography of scanned objects by photogrammetry compatible imaging.

The combined system offers numerous advantages over either technique separately including improved data collection efficiency, improved visualization, and the ability to extract dimensions from digital images.

Résumé

Les résultats d'une étude de démonstration de technologie sont présentés pour le groupe de modélisation humaine de Recherche et Développement pour la défense Canada (RDDC) Toronto. Le présent rapport décrit une méthode et un système d'intégration de données obtenues par balayage laser et photogrammétrie numérique. Il propose une solution intégrée au moyen d'un lecteur laser Cyrax, d'un appareil photo numérique Olympus 5050, du logiciel PhotoModeler et du logiciel PolyWorks d'InnovMetric, solution dont la démonstration est faite.

Le système proposé permet d'utiliser la photogrammétrie numérique pour augmenter la couverture du balayage laser et lui servir de relève, ajouter une couverture locale détaillée jusqu'à concurrence d'un modèle global de taille plus grande, assurer la texturation semi-automatique de modèles tridimensionnels (3D) (en réduisant le nombre de polygones dans certains cas), réduire la taille de la grille de balayage laser nécessaire dans le cas de certains objets et extraire des caractéristiques ou des dimensions d'images archivées.

La présente étude montre qu'il est possible d'obtenir une précision au niveau du centimètre à partir des données de photogrammétrie d'objets de grande taille (comme l'illustre le projet-pilote par la mesure de deux côtés de l'immeuble de RDDC Toronto). Des recommandations sont formulées pour la mise en œuvre de cette technologie, en particulier par le remplacement de photographies numériques d'objets balayés par des images compatibles de photogrammétrie.

Le système combiné offre de nombreux avantages par rapport à chacune des techniques prises séparément, dont la collecte plus efficace de données, une meilleure visualisation et la capacité d'extraire les dimensions d'images numériques.

Executive Summary

This study proposed and demonstrated an approach to integrate laser scanning and photogrammetry data so as to uses the advantages of both methods, and minimize the disadvantages.

Conceptually, when using the integrated approach, the overall framework of an object can be primarily measured with a laser scanner, while digital photogrammetry is used to augment and backup the scanning. This provides efficient data acquisition and processing, while providing global scale control and archiving of information.

Close range photogrammetry of a laser scanned object provides redundancy and convenient visual archiving of information. It also enables texture mapping (especially for flat objects) and the ability to extract features and dimensions at a later time.

Photogrammetry enables detail acquisition in areas where scanning is not feasible (such as confined areas, or those with a short line-of-sight).

Section 1 describes the background and objectives of this project.

Section 2 details the individual tasks and studies performed in this call up including:

- software (SW) and hardware (HW) acquisition and testing
- camera calibration
- pilot study to measure part of DRDC's building with the integrated system
- measurement and processing time and accuracy study results
- effect of laser scan grid size on accuracy
- test of using photogrammetry for cylinder measurements

Section 2 also describes the proof of concept for single-image photo texturing of models, the use of archived images for photo-texturing, and the integration of small local models to augment existing global 3D models.

Section 3 summarizes the project's findings and proposes the use of the integrated digital photogrammetry system for augmenting laser scanning of large objects such as the Canadian Forces Halifax class frigates.

Key findings are:

1. An integrated method for laser scanning and digital photogrammetry was successfully demonstrated using an Olympus 5050 camera, Cyrax laser scanner, PhotoModeler (PM) software and calibration grid, and Innovmetric's Polyworks software.

2. Global and local scale control are important in photogrammetry. We recommend adding a suitable scale reference with photo compatible targets where possible, in addition to using laser scanned control points.

3. Depending on the level of detail required and surface to be measured, the scanning point spacing grid might be increased from 0.020 metres (m) to 0.050 m without a major loss of accuracy in the photo models.

4. Approximately 0.75 hours post processing per digital image is required for registration, matching, and processing using PhotoModeler. The time will vary depending on the number of points and objects modelled per image.

5. Accuracy using photogrammetry without precise scale control (scale bar) or photo targets was found to be approximately 2-5 centimetres (cm) for large objects (side of building) using Cyrax laser scan for control points.

6. With precise scale bar and photo targets, accuracy less than 1 cm is possible, within the volume of the scale reference and calibration grid.

7. Photo texturing works well for planar objects, especially when an object can be captured completely in one image. Archived images from a non-calibrated camera can be used for photo texturing if control points are available from existing models or laser scan data.

8. PhotoModeler file exports are compatible with Polyworks and Rhino, but there is some trouble with trying to edit photo textured exported models with these packages.

Sommaire

La présente étude a proposé une approche pour l'intégration de données de photogrammétrie et de balayage laser et en a fait la démonstration, afin d'utiliser les avantages des deux méthodes et d'en réduire au minimum les inconvénients.

Sur le plan des concepts, lorsqu'on utilise l'approche intégrée, le cadre global de référence d'un objet peut être mesuré principalement au moyen d'un lecteur de balayage laser, alors que la photogrammétrie numérique augmente le balayage et lui sert de relève, ce qui assure l'acquisition et le traitement efficaces des données, tout en permettant la commande globale de l'échelle et l'archivage de l'information.

La photogrammétrie à courte distance d'un objet balayé par laser assure la redondance et l'archivage visuel pratique de l'information. Il permet aussi la projection de textures (surtout dans le cas des objets plats) et la capacité d'extraire les caractéristiques et les dimensions des objets à une date ultérieure.

La photogrammétrie permet l'acquisition de détails dans les zones où il n'est pas possible d'effectuer le balayage (comme dans les zones exiguës ou celles où la portée optique est restreinte).

La section 1 décrit le contexte et les objectifs du projet.

La section 2 précise les études et les tâches individuelles effectuées dans cette demande, dont :

- l'acquisition et la mise à l'essai des logiciels et du matériel;
- l'étalonnage des appareils photo;
- l'étude-pilote pour la mesure d'une partie d'un immeuble de RDDC au moyen du système intégré;
- les résultats de l'étude sur la durée et la précision des mesures et du traitement;
- les effet des dimensions du réseau de balayage laser sur la précision;
- l'essai de l'utilisation de la photogrammétrie pour prendre des mesures de cylindre.

La section 2 décrit aussi la validation de principe pour la texturation par images simples de modèles, l'utilisation d'images archivées pour la texturation et l'intégration de petits modèles locaux pour augmenter les modèles 3D globaux disponibles.

La section 3 donne un résumé des conclusions du projet et propose l'utilisation du système intégré de photogrammétrie numérique pour augmenter le balayage laser d'objets de grande taille, comme les frégates de la classe Halifax des Forces canadiennes.

Voici les principales conclusions:

9. Une méthode intégrée de balayage laser et de photogrammétrie numérique a été démontrée avec succès au moyen d'un appareil photo Olympus 5050, d'un lecteur laser Cyrax, du logiciel PhotoModeler (PM) et d'une grille d'étalonnage, ainsi que du logiciel PolyWorks d'InnovMetric.

10. Les commandes d'échelles globales et locales sont importantes en photogrammétrie. Nous recommandons l'ajout d'une échelle de référence appropriée avec cibles photo-compatibles, dans la mesure du possible, qui s'ajouterait à l'utilisation de points de repère par balayage laser.

11. Selon le niveau de détail requis et la surface à mesurer, la grille d'espacement des points de balayage pourrait passer de 0,020 mètres (m) à 0,050 m sans qu'il n'y ait de perte importante de précision dans les modèles photo.

12. Un post-traitement d'environ 0,75 heure par image numérique est requis pour l'enregistrement, la correspondance et le traitement au moyen du logiciel PhotoModeler. La durée du post-traitement dépend du nombre de points et d'objets modélisés par image.

13. La précision au moyen de la photogrammétrie sans commande d'échelle précise (échelle graphique) ou cibles photo a été établie à environ 2 à 5 centimètres (cm) dans le cas des objets de grande taille (côté d'un immeuble) au moyen d'un lecteur laser Cyrax pour les points de repère.

14. En présence de cibles photo et d'une échelle graphique précise, il est possible d'obtenir une précision inférieure à 1cm, à l'intérieur des dimensions de l'échelle de référence et de la grille d'étalonnage.

15. La texturation donne de bons résultats dans le cas des objets planaires, en particulier lorsqu'un objet peut être saisi au complet dans une seule image. Les images archivées prises par un appareil photo non étalonné peuvent servir à la texturation si des points de repère sont disponibles à partir des données de lecteurs laser ou de modèles en place.

16. Les fichiers exportés du logiciel PhotoModeler sont compatibles avec les logiciels PolyWorks et Rhino, mais des problèmes se posent lorsqu'on tente d'éditer des modèles exportés qui ont subi une texturation au moyen de ces progiciels.

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1 INTRODUCTION AND BACKGROUND

[1] In previous call-ups of Array's standing offer, detailed three-dimensional (3D) graphic models of two Canadian Forces (CF) helicopters were created or modified for the Defense Research & Development Canada Toronto (DRDC-Toronto): the Griffon helicopter, and the Sea King helicopter. These models were produced from supplied laser scanner data, collected using DRDC's Cyrax and ShapeGrabber laser scanners. These 3D graphics models are used for simulation, training, and for human engineering analysis such as conducting interior reach studies of pilot and seat positions for the aircraft.

[2] When these helicopters and other aircraft were scanned, they were also extensively photographed using digital cameras. They were photographed to provide archival information, and also for future use in photo texturing of the graphics models.

[3] During the processing of the Sea King scan data, it was noted that some objects, especially in the interior did not have complete laser scan data. This is likely due to space and or time limitations restricting the amount of laser scanning possible. As a result, some objects were modelled from visual (non rigorous) estimates and information in the digital images.

[4] Existing close range photogrammetry techniques and software allow dimensional measurements to be made from regular digital images, provided a few special requirements are met. Also, digital photogrammetry is well suited for integration with laser scanning, enabling certain advantages over either technique separately. A similar approach to combining laser scan and photogrammetry measurements is described in Beraldin et al. (2002)[1].

[5] As a result of some expected upcoming projects measuring CF's vehicles, especially the Halifax class frigates, this investigation was undertaken with the following scope of work:

1. Acquire the necessary photogrammetric hardware and software.
2. Develop working knowledge of the new system.
3. Perform combined laser and photgrammetric acquisition and modelling tests (scanning a local ship-like structure).
4. Experiment with various laser scan resolutions, which significantly affects scanning and processing time, and photgrammetric parameters.
5. Compare accuracy obtained from high-resolution laser scans, medium-resolution laser scans supplemented with photogrammetry, and low-resolution laser scans supplemented with photogrammetry.

[6] The project work began on June 1, 2003. This report describes the individual tasks and findings, and outlines some recommendations for using the combined system for future scanning projects.

[1] Beraldin, J., M. Picard, S.El-Hakim, G. Godin, V. Valzano, A. Bandiera and D. Latouche (2002). *Virtualizing a Byzantine Crypt by Combining High-resolution Textures with Laser Scanner 3D Data*. In Proceedings of VSMM 2002 (pp.3-14). Gyeongju, Korea

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2 DETAILS AND RESULTS OF INDIVIDUAL TASKS

2.1 Acquiring, Testing and Evaluating Photogrammetric Hardware and Software

2.1.1 Hardware: Olympus 5050 Digital Camera

[1] For acquiring digital images for the proposed integrated system, a new mid-range digital camera was required. Two Canadian companies specialize in close-range digital photogrammetry software – EOS systems of Vancouver BC (PhotoModeler Software) and Shape Quest Inc. of Ottawa ON (Shape Capture Software). Both manufacturers also sell bundled software/camera packages, which may also include the manufacturer's calibration of the camera's interior orientation parameters. Both manufacturers sell packages that bundle their software specifically with the Olympus 5050 digital camera, as shown in Figure 1.

Figure 1. Olympus 5050 Digital Camera

[2] The Olympus 5050 has a number of key features enabling it to be well suited for ship measurement applications including:

- Provides five mega-pixel resolution for accurate image target location and marking.
- Provides 3X analog zoom, focal length varies from 7-21 millimetres (mm), optimal for medium to large objects (like ship).
- Allows user to custom set all camera parameters and modes including disabling digital zoom, auto focus, etc. – i.e. ability to set and/or override important settings.
- Allows user to program custom modes saving groups of settings for consistent recall.
- Includes stable camera parameters related to physical construction of camera body.

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- Includes powerful yet easy-to-use user interface based on menus and soft-keys.
- Provides widely available manufacturer's support and accessories.
- Operates on commonly available, inexpensive AA batteries.
- Accepts variety of memory cards and supports numerous picture formats.
- Includes exceptional digital viewfinder that can be conveniently oriented for convenient high/low camera positions.
- Provides manufacturer calibration parameters and integrated tech support with software.

[3] The main disadvantage of the 5050 is that it uses a non-interchangeable lens (i.e. it is not single-lens reflex (SLR) with interchangeable lenses). This is true of all digital cameras in its price range. The approximate price of the 5050 is $1200-1500 CDN.

[4] For this call-up, the camera was purchased from Shape Quest Inc., as part of a bundle with Shape Capture V3.0 software and also including the manufacturer's calibration of the camera parameters. The calibration is provided on disk as a file with a series of empirical parameters defining a number of intrinsic camera characteristics such as pixel size, focal length, lens distortion and charge-coupled device (CCD) origin location. These parameters are used in the projects to improve the accuracy and reliability of the solutions of points. Alternate calibration procedures are provided in the on-line manual and help files.

[5] Note that the interior camera calibration parameters are valid at only a single focus and zoom position, with calibration normally possible only at the extreme (reproducible) focal positions, minimum and maximum zoom.

[6] The camera is fully compatible and supported by EOS Systems, maker of PhotoModeler, the other software package purchased for this call-up.

2.1.2 Common Features of Both Software Packages

[1] Both photogrammetry software packages (Shape Capture and PhotoModeler) contain the following common core capabilities and features:

- Loads, displays and enhances digital images.
- Marks points and features within images and registers them among multiple images of an object from different view points.
- Triangulates new points from images.
- Solves camera parameters and positions using a Bundle Solution.
- Calibrates known and unknown cameras – solves unknown calibration parameters.
- Creates, displays and edits a 3D polygon model from the point solutions.
- Adds semi-automated photo texturing to the model.
- Provides semi-automated and automated target detection, referencing and triangulation (details vary).
- Uses external control points for scale, orientation and/or photo orientation.
- Provides sub-pixel target location and marking.
- Loads and saves projects, troubleshoots projects.
- Displays/saves some quality and/or accuracy information about points and camera solutions.
- Exports 3D graphics models in various formats.

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[2] As well, each program has some special unique features, with those relevant to ship measurement applications described in the sections below.

[3] Initially, we planned to purchase only one of the two available software packages for this project. After conducting preliminary research with demo versions of both software packages, we concluded that both packages were complementary and may contain unique features. The Shape Capture software was used by Canada's National Research Council (NRC) for a task similar to that being proposed, described in the paper referenced previously. PhotoModeler was also used by the author in previous applications, similar to the one proposed.

[4] Given the relatively small incremental cost of obtaining both packages compared to the project cost, we decided to purchase both packages, and include a preliminary evaluation of each program as part of the investigation.

2.1.3 Software Package #1: Shape Capture

[1] As mentioned previously, Shape Capture V3.0 (SC), was purchased in a package with a calibrated Olympus 5050 digital camera.

[2] The SC software was installed on two computers—a high-end dual-Athalon processor desktop computer and an Intel Pentium laptop computer to test it using two common configurations and also under two common operating system platforms – one being Windows XP Professional (the desktop), and the other (lap-top) being Windows 2000. The software was found to function effectively under both configurations and platforms.

[3] Several objects were measured with the SC system including a file cabinet, wood desk/table, and a simple office chair. Also, a CF18 model airplane with detailed laser scan data was used to test the single-photo texturing capabilities and camera solving modes of both programs.

[4] The software has a number of interesting features (beyond the basic capabilities) such as sub-pixel edge detection, automated target location and registration, and single-photo modelling capabilities.

[5] Figure 2 shows a screen capture of a sample project in SC, this one being the solution of chair dimensions of a DRDC lab chair measured using SC, and previously laser scanned using the Cyrax scanner.

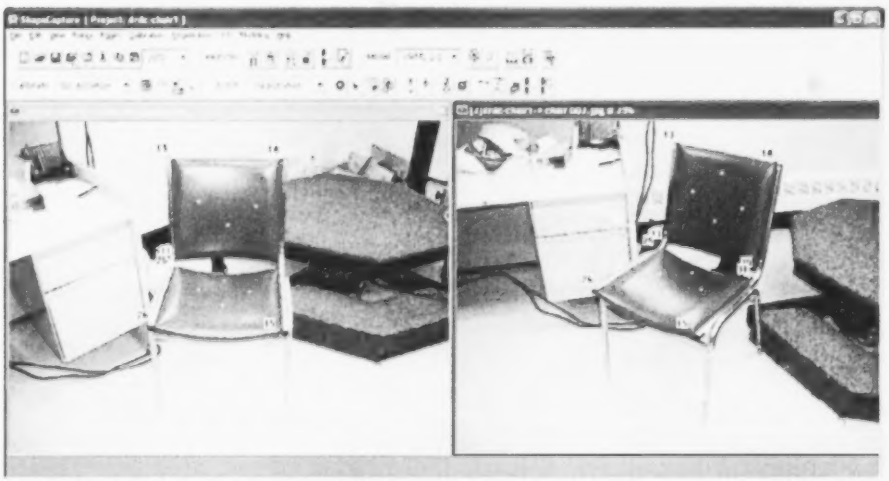

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Figure 2. Sample Shape Capture Project

[6] Note that several simple (non retro-reflective) dot targets were added to the chair to assist in multiple image registration. The targets are not required for either software package, provided suitable naturally identifiable, locatable points are found on the object – typically point or corner objects that can be unambiguously identified and located from multiple camera viewpoints.

[7] The model was solved by exporting control points from a polygon model created using Innovmetric's Polyworks software package, from Cyrax laser scan data of the chair. Several check-distance measurements were made of features on the chair comparing the laser-scan and photogrammetry solutions. A sample of eight check distances was found to vary randomly up to 2 cm from the laser scan data.

[8] It was found to be fairly challenging to locate points in the images with SC for several reasons – it is difficult to adjust the zoom factors and/or resize images and windows, the point marking magnification window introduces significant degradation of the image quality, and colour images are displayed in monochrome. Also, it is necessary to manually keep track of point numbers and locations, a challenging task when many points are present.

[9] Although it may be possible to use SC for the proposed integrated system and applications, or for other applications, additional tests and consultation with the manufacturer are required. Given the limited time constraints of this call-up, these tasks were left as a future exercise.

2.1.4 Software Package #2: PhotoModeler

[1] As described previously, PhotoModeler (PM) V5.0 was purchased from EOS Systems in Vancouver for use in this call-up with the Olympus 5050 camera. Figure 3 shows a typical PM project screen capture, in this case, the single-photo texturing test of a CF 18 model airplane. More specific details on this application are described in a later section on single photo texturing.

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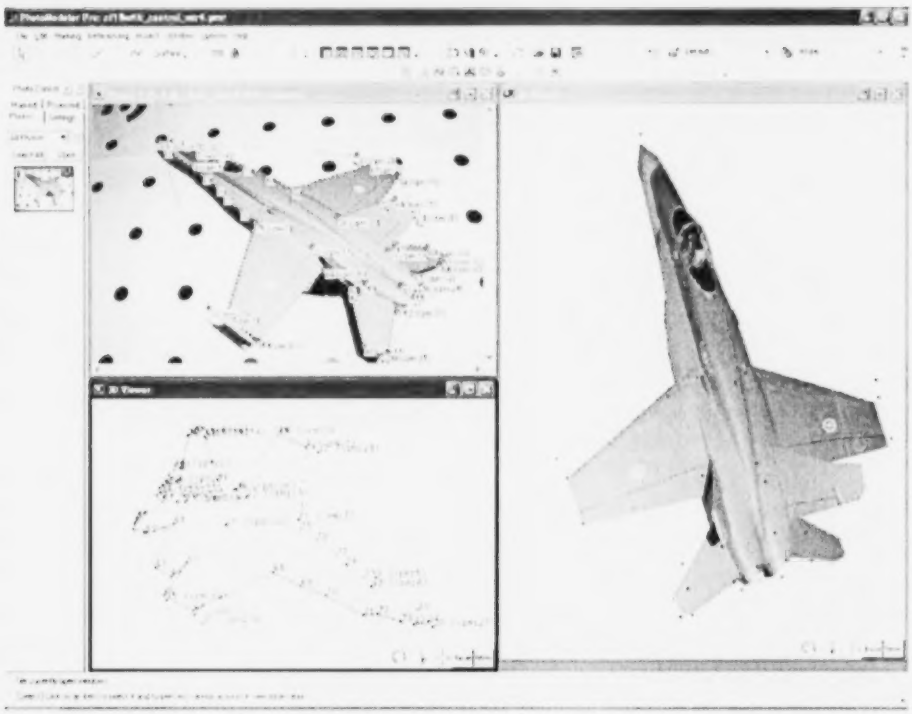

Figure 3. Sample PhotoModeler Project

[2] In addition to the common core functionality described previously, a number of additional advanced features unique to PM were used for the remainder of this call up including:

- Improved photo texturing: blending, feathering, warping, segmenting and intelligent selection from multi-photo sets.
- Automated camera calibration with coded targets, not requiring external measurements or sensors.
- Special target modes to mark, reference, and use common edges, curves, cylinders, and lines in addition to points.
- Flexible point selection and referencing techniques.
- Improved window and image zooming, tiling, improved magnifier, etc.
- Easy-to-use yet powerful constraint definitions: coplanarity, collinearity, parallelism, fixed distances and angles.
- Post-processing scale, rotation and translations.
- Advanced Non-Rational Uniform B-Spline (NURBS) modelling – revolutions, boundary patches, path definitions, etc.
- Photo-textured NURBS capability.
- Advanced reporting, auditing, and quality information display and exporting.
- Advanced troubleshooting modes.

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- Automated use of digital camera EXIF information (see below for more information).

[3] Other advanced features for automated target detection, referencing and surfacing were present but not required or suited for ship measurement applications. The above capabilities provide improved efficiency for the proposed tasks, and thus PM was used exclusively for the remainder of the call-up.

2.2 Calibration of Olympus 5050 Digital Camera

2.2.1 Overview: Need for Calibration

[1] Detailed explanations of digital camera calibration techniques, advantages and methods are described in the PM manuals and on-line help files. They are also well covered in the PM-provided tutorials and videos.

[2] The frequency of calibration depends on factors such as the required accuracy, physical handling of the camera, external environment of the project site, and the technical experience and capability of the software's operator.

[3] It is critical to note that calibrations are only valid for a unique focal length and zoom position. As specific intermediate zoom positions are not accessible, calibration is performed at minimum and maximum zoom positions. Other specific calibration limitations and requirements are described in the PM manual.

[4] For this call-up, as the calibration data was not purchased from the PM manufacturer (as opposed to the SC manufacturer) for the Olympus 5050, lab calibration at DRDC was required. Two methods were used, each described below.

2.2.2 Method #1: Floor Poster Grid Method

[1] A large pre-plotted target grid was purchased from PM for use in camera calibration. This 90 x 90 cm sheet can be attached to the floor for convenient use in camera calibration. Figure 4 shows the PM calibration project for the floor sheet, including some sample images.

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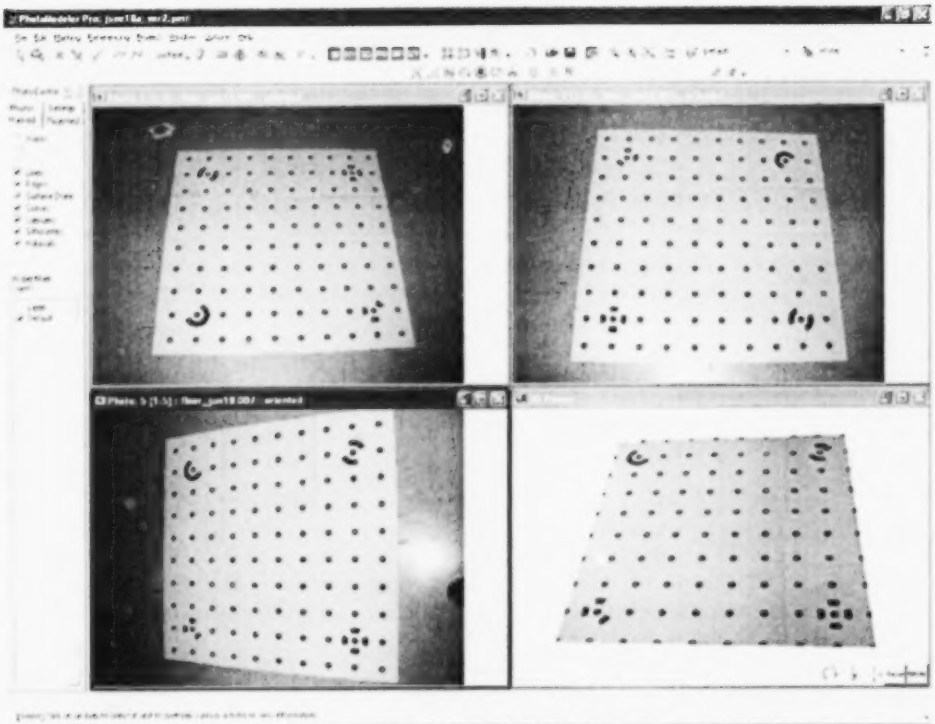

Figure 4. Floor Grid Calibration Project in PhotoModeler

[2] In total, eight images of the sheet were taken with the camera, horizontal and vertical images from each of four primary directions. This is in accordance with the manufacturer's instructions.

[3] The calibration processing is fully automated, as a result of the four coded targets in the image (located at the corners). The ability to use coded targets (in addition to using them in the calibration routine) is available as an add-on from EOS Systems. The main advantages are that target location, naming, and referencing are automated with coded targets, saving significant processing time and effort. The disadvantage (besides the add-on cost) is the requirement to use large targets with coded marks.

[4] As the calibration requires an even uniform grid spacing, the presence of folds in the paper is not ideal, but likely sufficiently accurate for our modelling purposes. For higher accuracy, mounting the sheet more rigidly (such as poster mounting) is recommended.

[5] This calibration was successful, with a maximum point measuring error of 0.236 pixels, considered 'good' according to the manufacturer's guidelines. Due to physical lab space restrictions, this calibration could only be performed at the maximum zoom position (longest focal length). Thus, this method is best suited for use with small models, such as the CF18 model project described later.

[6] The use of a pre-plotted sheet is advantageous, as it requires no additional hardware such as a slide projector. This makes it suited to on-site calibration or verification, or to use as a backup method to the more accurate grid projection method described below.

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[7] The disadvantage of the pre-plotted grid is that it is of a fixed size, not ideal for high-accuracy (e.g. under 1 cm) projects with objects larger than the overall grid size.

2.2.3 Method #2: Slide Projected Grid Method

[1] The standard PM software package includes a 35 mm slide for use in an ordinary slide projector. This enables a scalable, large size image of the grid to be projected onto a flat, light-coloured wall. This process was used twice at DRDC, once on a flat-white board in a conference room, and once on a painted wall in a laboratory.

[2] For both cases, a DRDC photo specialist carefully cleaned the slide projector. This cleaning was to prevent dust or dirt in the optical train from being misidentified by PM as a photo target.

[3] Figure 5 shows an image of the projected grid in the laboratory.

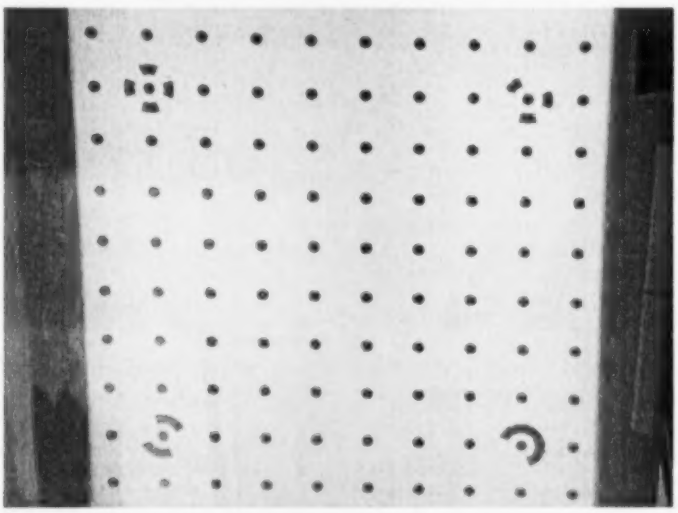

Figure 5. Calibration Grid for PM Projected With Slide Projector

[4] It is important when using the Olympus 5050 to correctly set the exposure settings to not equalize the image, nor to sharpen it excessively. Also, it is critical that the focus and zoom are locked, and that the built-in flash is disabled.

[5] A total of 12 images were taken, from left and right, high-medium-low positions, at both horizontal and vertical orientations.

[6] The use of a commercial white board as a background was unsuccessful, as the slide projector's bright light caused a spot reflection in the images due to the polished, reflective white-board surface. The use of an ordinary light coloured wall however, was successful, with a maximum error of 0.361 pixels, below the manufacturer's suggested limit of 1.0 pixel for a "good" calibration.

[7] Note that the calibration was performed at both maximum and minimum zoom positions.

[8] Figure 6 shows the PM project for the lab wall slide-projected grid.

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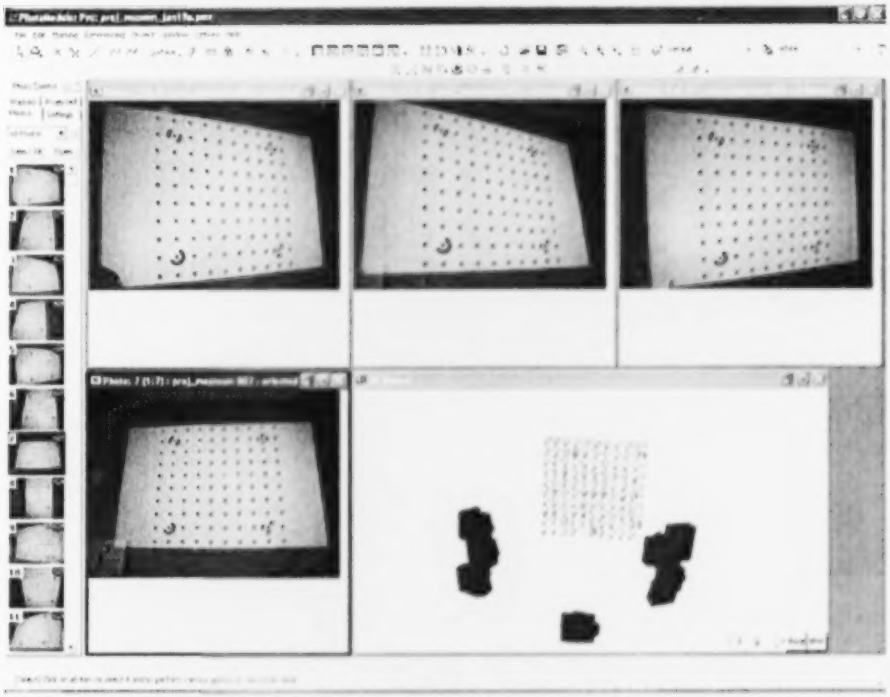

Figure 6. Slide Projected Grid Calibration Project

[9] The calibration parameters from this calibration were successfully used for the remainder of the call-up's tests and studies. Note that the PM software can display and/or export the actual relative or absolute camera positions and orientations.

[10] The PM calibration routines and techniques are powerful, yet easy to use and solve automatically, offering some important advantages over SC, including its use of free-network solutions to provide scale invariance (i.e. no need for external sensors or information like a laser scanner or tape measure).

[11] An additional calibration method is possible, when a slide projector is not convenient. PM provides an image of the calibration grid that can be transferred or printed to a transparency that can be projected on a wall using an overhead projector. Overhead projectors are typically more commonly available than slide projectors. This method has been used successfully in other projects by the author.

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2.3 Combined Scanning and Photogrammetry of DRDC Building (Pilot Project)

2.3.1 Overview

[1] The main demonstration of technology for this call-up, involved the combination of laser scanning and photogrammetry to create a simple, photo-textured (PT) model of part of a DRDC-Toronto Building, as shown in Figure 7.

Figure 7. Digital Image of Building Facades for Combined Laser Scanning and Photogrammetry

[2] The size, standoff distance and typical features are similar to those that might be encountered when scanning a Halifax-class Canadian Forces frigate.

[3] Some objectives of this activity were to:

- Demonstrate feasibility and proof of concept for integration
- Refine integration methods and techniques with PM software
- Identify advantages, weaknesses, and special requirements of integrated methods
- Assess efficiency and time of integrating photogrammetry
- Assess required control point density and laser-scan grid size
- Use as training exercise
- Test post-project addition of details to model

[4] The details of these tasks and results are described below, and in Section 3.

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2.3.2 Laser Scanning of Building

[1] Laser scanning of the building's exterior took place June 24, 2003, from 5:00-7:00 pm at DRDC Toronto. A DRDC non-contact Cyrax laser scanner, shown in Figure 8, was used to scan the building.

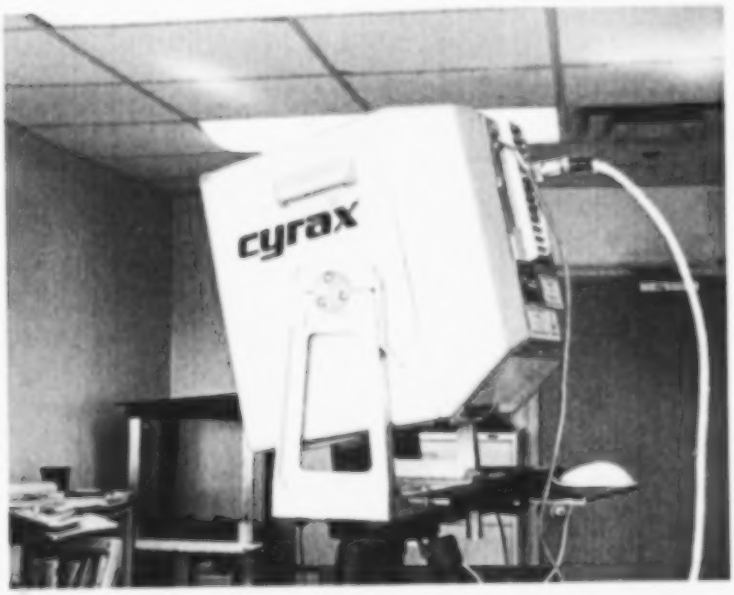

Figure 8. Cyrax Laser Scanner in Lab

[2] The building was scanned with a nominal 20 mm square grid point spacing, from a total of eight scanner positions. Image and laser scan overlap were scanned sufficiently to use Innovmetric's IMalign to combine and register the scans. An additional area of detail, including two auxiliary air conditioners and railings surrounding them was scanned at a higher density using a 10 mm square grid. These data were used to test the post-processing merging of a detailed object to the overall building model, and to test the feasibility of using photogrammetry for railing measurements.

[3] The laser scanning required approximately two hours at DRDC, including set-up and moving of the scanner. During this time, access to and from that area of the building was secured to avoid unnecessary eye exposure to the Class II laser, and also to prevent obstruction of the laser scans. The scanner was operated by DRDC-Toronto Specialist Robert Mertens. One scanning location is shown in Figure 9.

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Figure 9. Laser Scanning of Building Using Cyrax

2.3.3 Photogrammetry of Building

[1] Photogrammetry imaging of the building exterior took place June 20, 2003 from 9:30-10:00 am. A total of 26 images were taken, covering the area of study from multiple viewpoints. Of these, eleven were eventually used in the final model. Additional images were required due to the obstruction of views from trees and their shadows.

[2] Figure 10 and Figure 11 are two digital images used in the photogrammetry project. Multiple image viewpoints were taken of all regions in the building to enable post-processing triangulation of points and features. Also, additional images of the air conditioning units were taken for demonstrating the ability to add areas of detail to larger models.

[3] All images were taken using the minimum camera zoom (for widest coverage, shortest focal length) and all images were taken with identical camera settings and parameters, saved as a set in the 'MyCamera3' pre-set directory on the Olympus 5050. Proper selection and control of settings was found to be critical for obtaining accurate results.

[4] Note that the photogrammetry data acquisition required approximately ¼ the amount of time as laser scanning. This time advantage however, is offset by the additional processing time. More discussion of time considerations is found later in this report.

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Figure 10. Sample Photogrammetry Image for Study

Figure 11. Additional Photogrammetry Image of Part of Building Measured in Study

2.3.4 Processing and Analysis of Results

2.3.4.1 Overview and Methods of Processing Data

[1] The laser scan data was processed using both Cyclone software from Cyrax, and Polyworks software from Innovmetric.

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[2] The scans were stored internally on the Cyrax laptop, and exported to Polyworks using PTX format. Polyworks split the PTX format into 21 .pf files that were locally and globally aligned together in Innovmetric's IMalign. The individual alignment standard deviation of the scans was 2-4 mm. Once aligned, overlap was reduced to the recommended minimum, and the model was polygonized using IMmerge. The resulting Polygon model from the 20 mm square grid is shown in Figure 12.

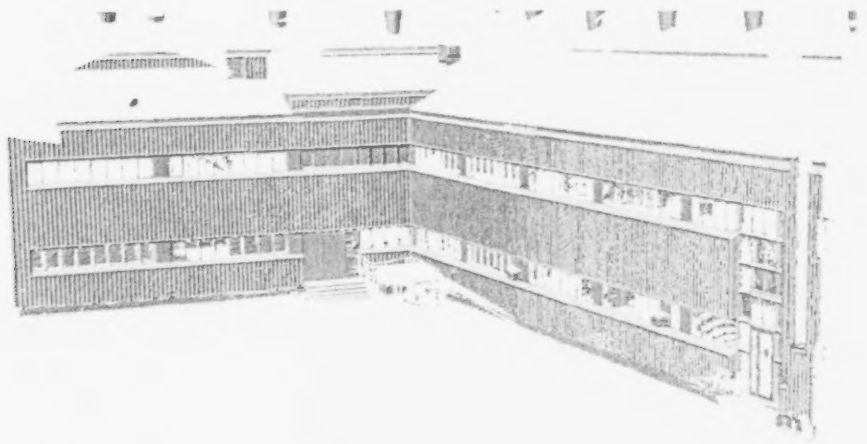

Figure 12. Polygonized Model from Cyrax Laser Scan Based on 20 mm Grid

[3] Once merged, the polygon was imported to Innovmetric's IMinspect to transform it to a convenient global 3D coordinate system. Planes were fit to each side of the building, and intersected to find a vertical axis at the common corner. A plane was also fit to some ground data to use as a base or zero ground plane. The three planes were intersected to locate the origin at ground level of the common building corner (near the large external AC units).

[4] The last processing step was to identify features in the polygon model that could be easily marked in the digital photos, solve their point location in IMinspect, export them to an ASCII text file and import them as control points in PM. Additional points used as check points for accuracy determination were also selected. Corners of windows and some building corners were ideal for these purposes. Total post-processing time for the laser scan data was approximately three hours.

[5] The digital images were processed in PM, with the project screen capture shown in Figure 13.

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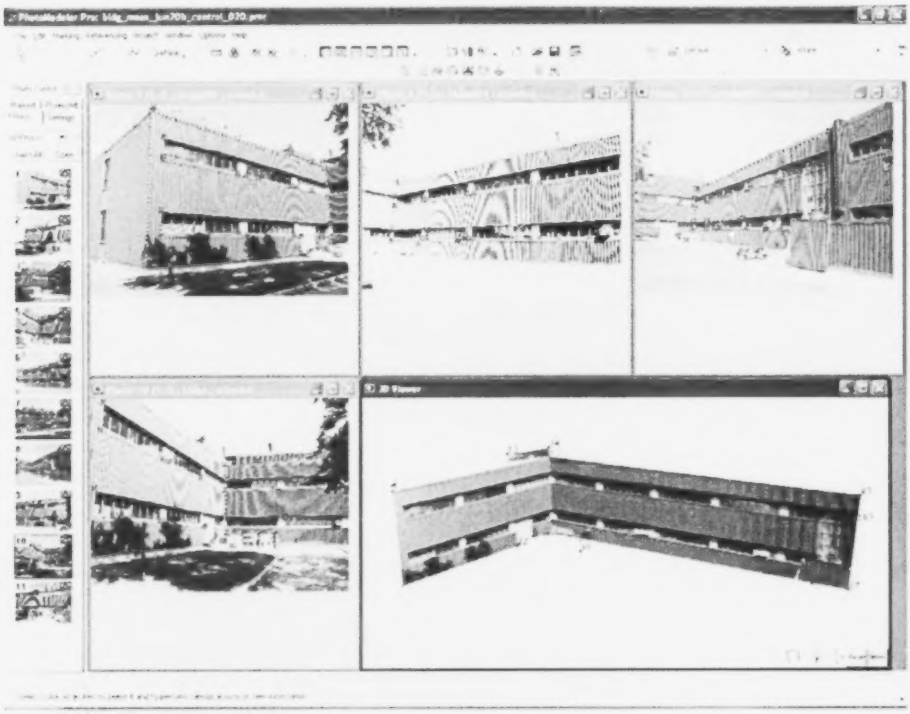

Figure 13. PhotoModeler Project of Building Images

[6] A total of 11 images were used to model the building, and enable triangulation of additional features in the images. The camera was described by the projected slide calibration from the lab walls, detailed previously.

[7] In PM, the post-processing required manual marking of common points (recommended minimum of 10 points per image) among the images. Also, the control points from the laser scanning were imported, marked and identified as control points. More details on the solution and integration method are described below.

2.3.4.2 Measurement and Processing Times

[1] As noted earlier, data acquisition time for the study area of the building exterior required two hours for the laser scanner and 30 minutes for Photogrammetry.

[2] Processing the data required approximately three hours for the laser scanner (using Polyworks) and approximately nine hours for photogrammetry using PM. The photogrammetry post-processing is longer as it requires more user intervention to identify, mark and register points accurately among the images. Also, defining and checking constraints and solutions can be time consuming depending on the situation, and the experience of the operator. As a general rule of thumb, from this study, it was found that approximately 0.75 hours per image should be allowed for photogrammetry post-processing.

[3] The actual time requirements depends not only on the number of images, but also the number of points per image needed for the graphics modelling, which in turns depends on the number of objects in the images and their complexity. Also, the number of unambiguous, clearly definable points and features in the images can have a significant effect on the processing time required.

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2.3.4.3 Integration Method

[1] The integration of laser scan data and photogrammetry requires a common global coordinate system. The easiest way to achieve this is to define the coordinate a system based on the laser scan data, select points on features that can be matched to points in digital images, and export these to PM.

[2] These exported laser scan points are then marked as control points in the images using PM, enabling the photogrammetry points to be solved in the laser scan coordinate system. A minimum of four control points are needed, with additional points providing some redundancy, and improved scale coverage across the area of interest. Figure 14 shows nine points in the laser scan model selected as control points, seven of which were eventually used to integrate the laser scan and photogrammetry data.

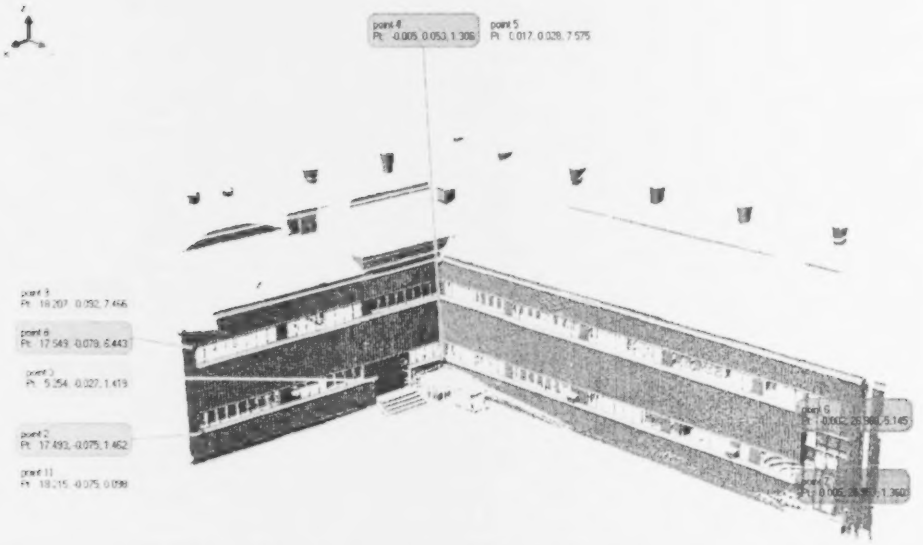

Figure 14. Control Points Used for Laser Scanning and Photogrammetry Integration

[1] The accuracy of the integration depends upon how well points can be corresponded between the laser scan model and photogrammetry images. Also, the points chosen must be clearly locatable from multiple image views. Points like features, including sharply defined corners are best suited for this location, or artificial points (targets) can be placed on the objects. Using artificial targets can also enable PM sub-pixel edge detection routines to be used, enabling higher accuracy.

[2] In the photogrammetry solutions, defining proper scale is important to obtaining the maximum dimensional accuracy. Ideally, scale definition will use a distance measurement that spans a bounding box diagonal length of the area of interest. In practice, this can be quite difficult. Laser scanning enables a large distance to be used for scale control, though the absolute accuracy of the laser scanner will have a direct impact on the solution accuracy.

[3] For PM modelling of smaller objects, such as when adding areas or objects of detail to larger models, there are a number of options for scale definition, described later in the report.

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2.3.4.4 Grid Size vs. Accuracy Analysis and Results

[1] An important objective of the pilot study is to determine the maximum laser scanner grid size that provides acceptable results for objects similar to the one studied. Maximizing laser scan grid size can significantly reduce scanning time and costs of measuring large objects. If specific objects or areas of detail can be added with photogrammetry, and also using photo texturing, significant time and cost savings may result.

[2] To determine the effect on photogrammetry model accuracy depending on laser scanner grid size, extensive data analysis was performed. Using IMalign, the original 20 mm square grid was decimated and resampled at larger grid sizes – 40 mm, 50 mm, 100 mm, and 200 mm. For each grid size, a new polygon model was created. Models for three larger grid sizes are shown in Figures 15-17. Note the obvious degradation of quality and loss of detail as the grid size increases.

Figure 15. Polygonized Building Model Using 50 mm Grid

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Figure 16. Polygonized Building Model Using 100 mm Grid

Figure 17. Polygonized Building Model Using 200 mm Grid

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[3] To quantify the loss of accuracy compared to grid size, 37 check points were selected of features that can be identified and measured in the photo model. The location of these check points are shown in Figure 18.

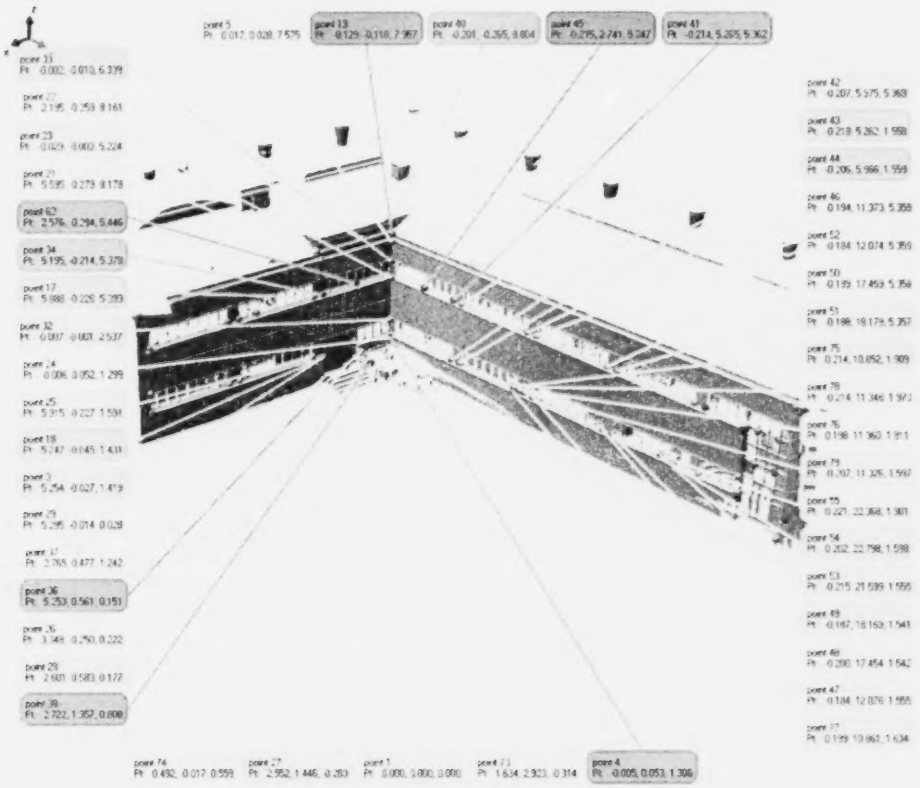

Figure 18. Control and Check Points Used in Accuracy Study from IMinspect

[4] The PM solutions of these points are compared to their values from the 20 mm laser scan grid. The mean Root Mean Square (RMS) error with respect to the laser scan data for each grid size is shown in Figure 19. Also shown in that figure is the standard deviation of the error for each grid size.

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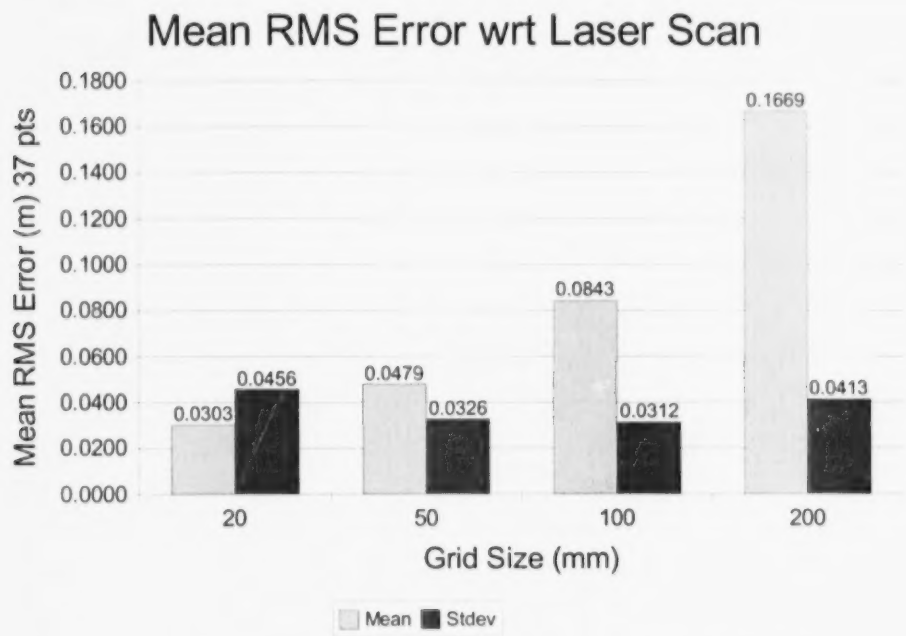

Figure 19. Results of Accuracy vs. Grid Size Study Compared to Laser Scan Data

[5] Notice the significant jump in accuracy degradation from a 50 mm grid (47.9 mm RMS error) to 100 mm grid (84.3 mm RMS error).

2.3.4.5 Addition of Extra Detailed Models to Main Model

[1] One potential advantage of the integrated method is the ability to add areas or objects of detail to laser scanned models by using photogrammetry. This enables less detailed large global models to be easily augmented with more detailed specific objects. Another advantage is the ability to go back to the images at a later date and add objects of interest, or extract certain measurements or dimensions, for example to check certain dimensions.

[2] To prove and test this capability, two air conditioning (AC) units, one large external unit, shown in Figure 20, and one small window unit, shown in Figure 21 were imaged and solved as separate PM projects to be integrated into the larger building model.

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Figure 20. Sample Image of Large Air Conditioning Unit

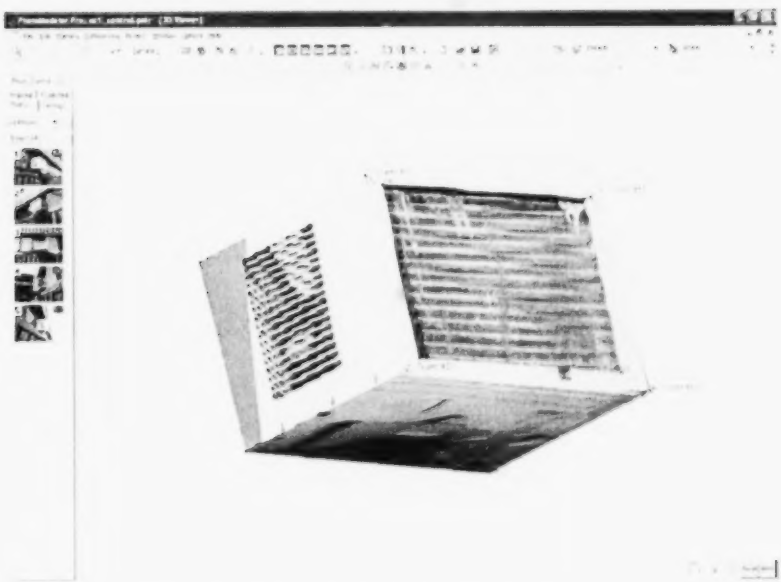

Figure 21. Sample Image of Small Air Conditioning Unit

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[3] To add the large AC unit and check its dimensions, the special 10 mm grid laser scan data was processed using IMalign, in the same coordinate system as the larger 20 mm laser scan grid. Corner points of the large AC unit were selected and exported to use as control points for PM. To improve the locating of the corners in the model, planes were fit to polygons to define the sides of the large AC unit. These planes were then intersected using IMinspect to accurately locate the object's corners. The resulting six points, five of which are used for control in PM, are shown in Figure 22.

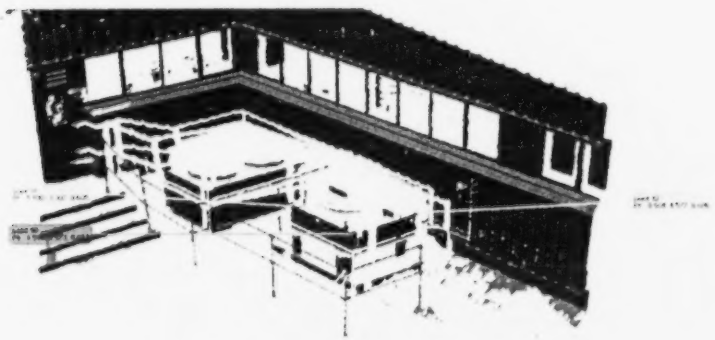

Figure 22. Control Point Locations for Adding Large AC Model Using Photogrammetry

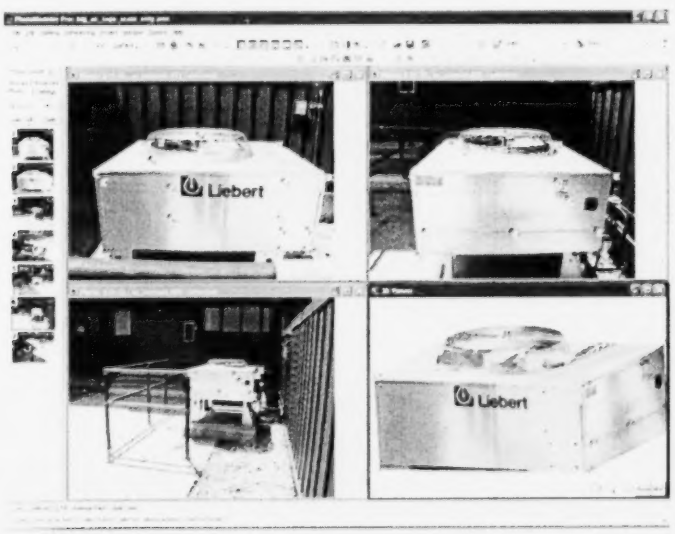

Figure 23. PhotoModeler Project for Modeling Large AC Unit

[4] Figure 23 shows a screen capture of the PM project for the large AC unit. Seven images were used in this project.

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[5] For the small AC unit, five images were used, with the PM project screen capture shown in Figure 24. Four control points were selected from the 20 mm grid laser scan model to use for control and orientation of the small AC.

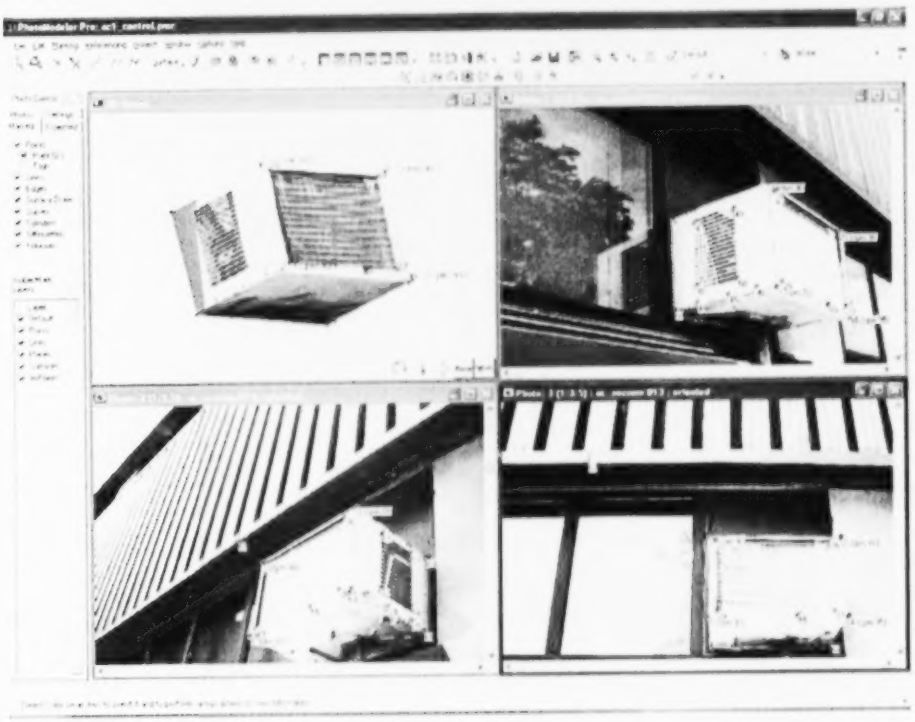

Figure 24. PhotoModeler Project of Small Air Conditioner

[6] Figure 25 shows the non-textured small AC model integrated into the large building model.

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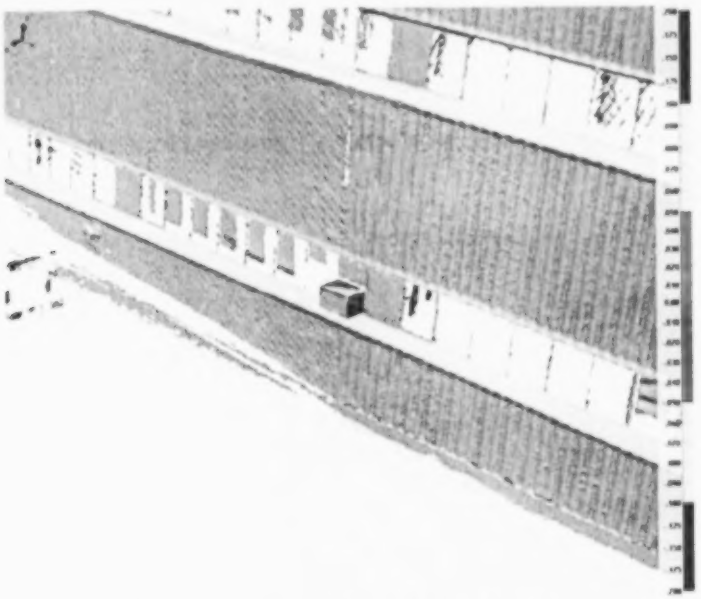

Figure 25. Non-Textured Addition of Small AC to Building Model

[7] To assess the accuracy of the integrated objects, measurements of the length, width and depth were measured using a tape measure. The expected accuracy of these measurements is 0.002 m.

[8] PM allows scale and orientation of photo models to be defined in various ways. The most common method is by defining a single unique scale, and optionally three points for orientation. Another common method is by using control points to define scale and orientation. Also, a combination of control and scale constraints may be used. As a result, for the small model integration, three solution methods were possible – control points, scale definition (i.e. tape measure in this case) only, or both.

[9] The results of the comparison using the three methods compared to the tape measured distance for both the large and small AC units are shown in Figure 26. The mean, max, and standard error of the six check distances are shown. Note that the addition of a unique scale measurement improved the dimensional accuracy significantly. This is due to the improved local accuracy of the tape measure compared to that derived from the Cyrax (3-6 mm error).

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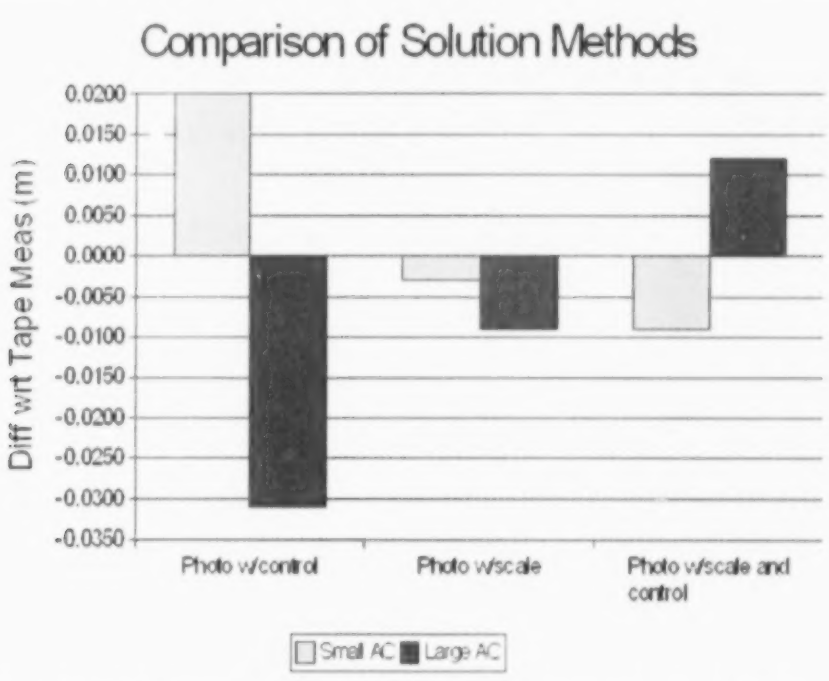

Figure 26. Accuracy Comparison of Solution Methods for Large and Small AC Units

2.3.4.6 Use, Results and Application of Cylinder Measurements

[1] The solution of cylinders using PM requires using a special marking mode in the program. This is necessary since cylinders typically do not contain points that can be uniquely matched from multiple viewpoints. Instead, this feature in PM enables the edges of cylinders to be marked (two points on each side) from multiple viewpoints.

[2] The capability to solve cylinders is important to assess, as ship measurement applications contain numerous objects that are best represented as cylinders.

[3] To test this capability, an area of railing around the large AC was imaged and added to the large AC model. Figure 27 and Figure 28 are two images used for the cylinder measurement. According to the PM instructions, it is important to image cylinders from viewpoints covering at least 90 degrees of arc of the cylinder. Thus for horizontal cylinders, images from various heights are required, for vertical cylinders, images from a variety of horizontal viewpoints are needed.

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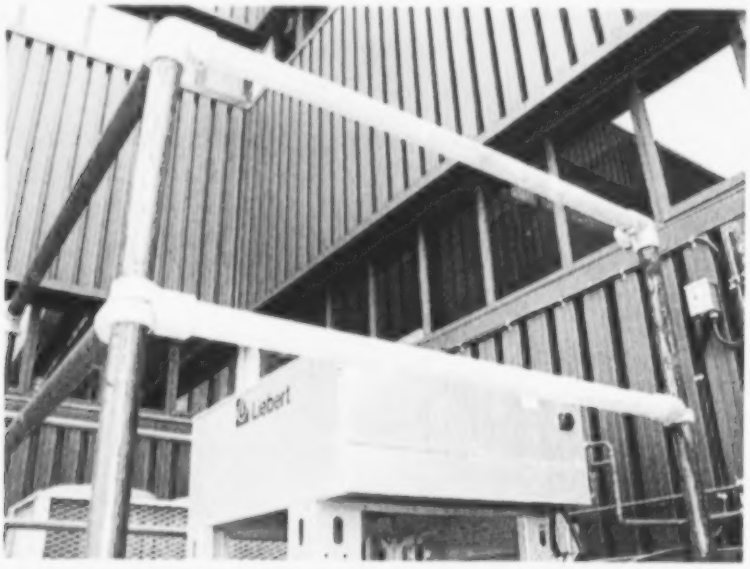

Figure 27. Photogrammetry Image of Railing and Large Air Conditioned

Figure 28. Additional Photogrammetry Image of Railing and Large Air Conditioned

[4] To assess the accuracy of the cylinder solutions using photogrammetry, the resulting PM cylinders are compared to those derived from the laser scan data using IMinspect. Cylinders were fit to the laser scan data using both fixed and non-fixed radius modes. The fixed radius constraint generally provides significantly more accurate cylinders.

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[5] The raw PM cylinders compared to the laser scan data is shown in the error map in Figure 29.

Figure 29. Error Map of Photogrammetry Solution of Railings Compared to Laser Scan Locations

[6] Note that the PM cylinders are compared to the fixed radius laser scan data fit cylinders. The errors are significant, up to 20 cm magnitude. To further assess these errors, the radius fits are compared from PM to both the fixed and variable radius solutions from the laser scan data, with the results shown in Figure 30. Note the maximum radius size error is 3 cm, resulting in a potential 6 cm diameter error. This likely contributes significantly to the errors shown in Figure 30.

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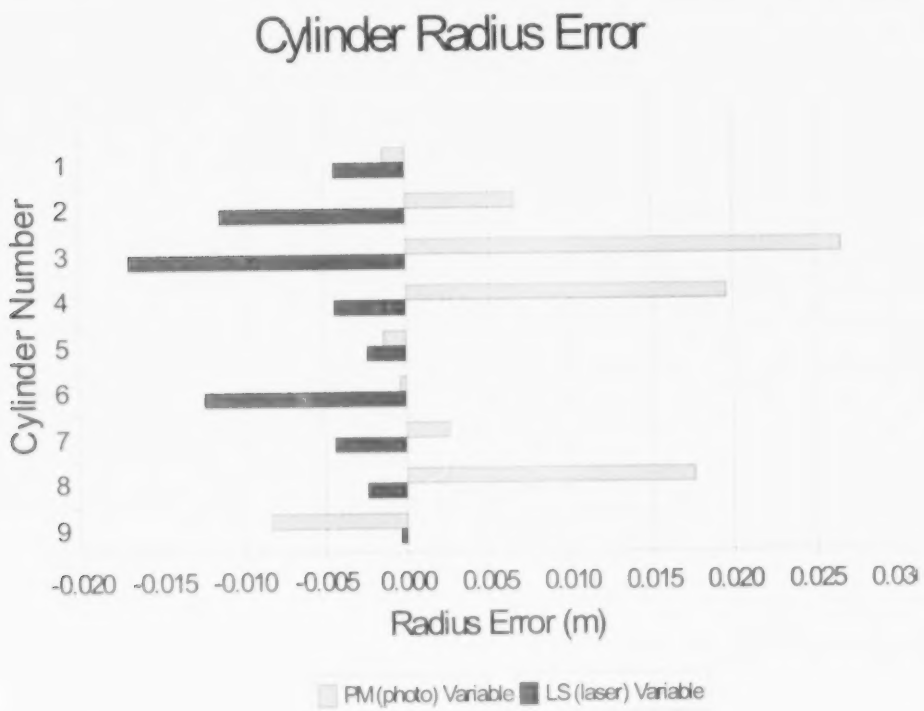

Figure 30. Cylinder Fit Radius Errors for Railing Components

[7] For accurate conventional 3D modelling of the railing, it is advantageous to accurately define the centerline of the cylinders, and revolve or sweep surfaces using a known or measured radius/diameter. With this approach, accurate placement of the nodes, or points of intersection of the cylinder's centerlines is important.

[8] To evaluate this capability using PM, nodes were solved from the cylinders using both PM, and laser scan data and compared. The node locations are shown in Figure 31, and the accuracy comparison is shown in Figure 32. Note in this case, the difference compared to the fixed radius cylinder solution is on average approximately 4 cm different, significantly better than the raw comparison of Figure 29 (up to 20 cm).

[9] This test indicates that PM and photogrammetry are useful for solving cylinders to use for centerline and node determination (enabling accurate surfacing), when laser scanning is not practical.

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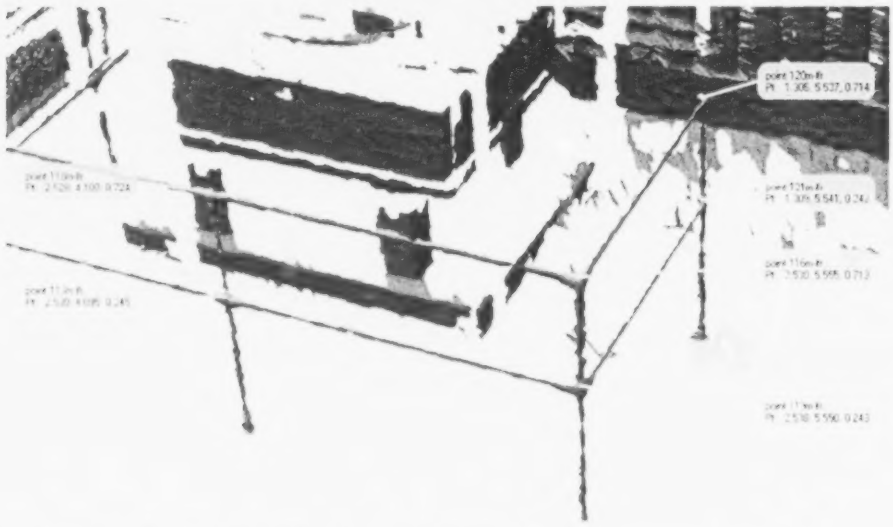

Figure 31. Locations of Six Nodal Points for Railing Centerlines

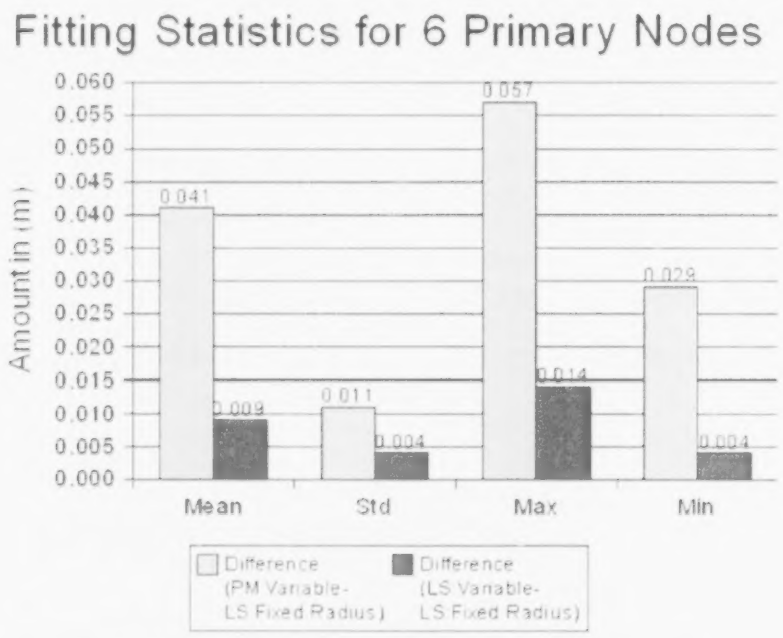

Figure 32. Spatial Error in Nodal Point Locations for Cylinder Centerlines

2.3.4.7 Semi-Automated Photo Texturing of Models

[1] Another key objective of this call-up was to demonstrate and evaluate the ability of PM to provide semi-automated photo texturing of 3D models. Photo texturing is widely used in 3D graphics to

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reduce polygon counts of models while still providing realistic looking details. Although the models are considerably less dimensionally accurate (as they often lack the depth features of dense polygon models), the reduced polygon count is important, especially for real-time simulations (like flight simulators).

[2] Figure 33 shows the resulting polygon model of the building, and the large AC unit. Note the faces of the buildings contain only 6 polygons. The 20 mm grid model contains 1.8 million polygons (for comparison). Figure 33 does not provide much realism as a building façade, but, the addition of photo-texturing (PT), as shown in Figure 34 is quite realistic with minimal increases in file size and overhead memory or graphics resources needed.

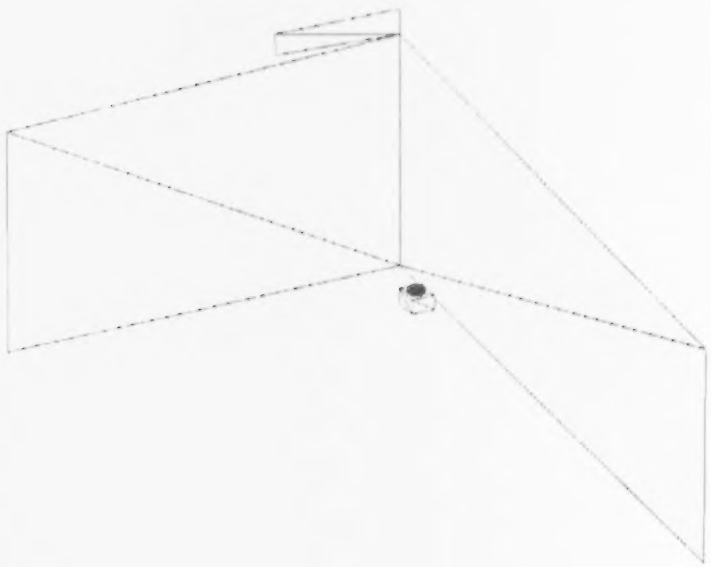

Figure 33. Shaded Polygon Model from Photogrammetry Solution of Building

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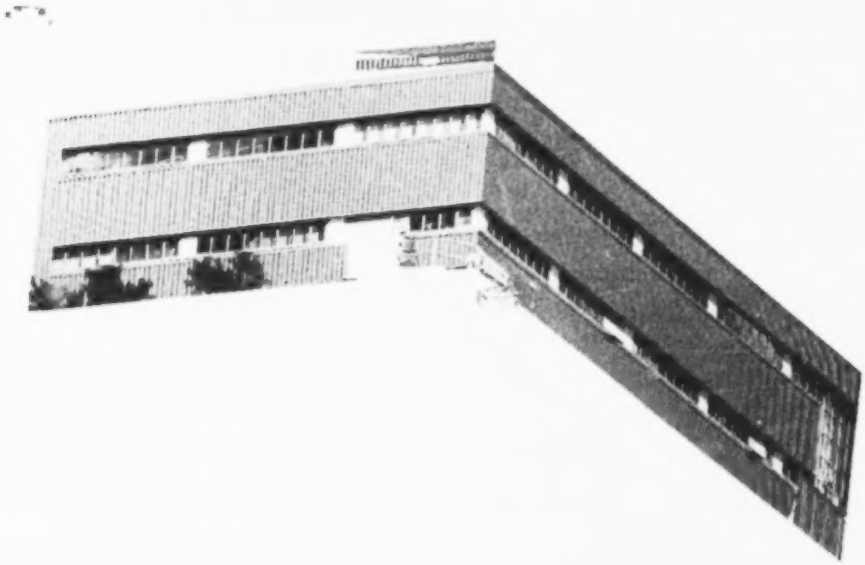

Figure 34. Model from Figure 33 with Photo Texturing

[3] Figure 35 shows an enlargement of the large AC detail area, showing the ability to merge two PT models, one large, one relatively smaller.

Figure 35. Insertion of Large Air Conditioner Model Into Large Building Model

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[4] PM stores texture maps in the widely used .jpg format, using a technique called UV mapping, thus enabling the maps to be edited, enhanced, and/or corrected using photo editing software such as Paint Shop Pro.

[5] This capability is illustrated in Figure 36, where airbrush tools in Paint Shop Pro were used to remove tree-shadows from the texture map for the building model. Other programs such as PhotoShop could also be used to enhance the texture mapping.

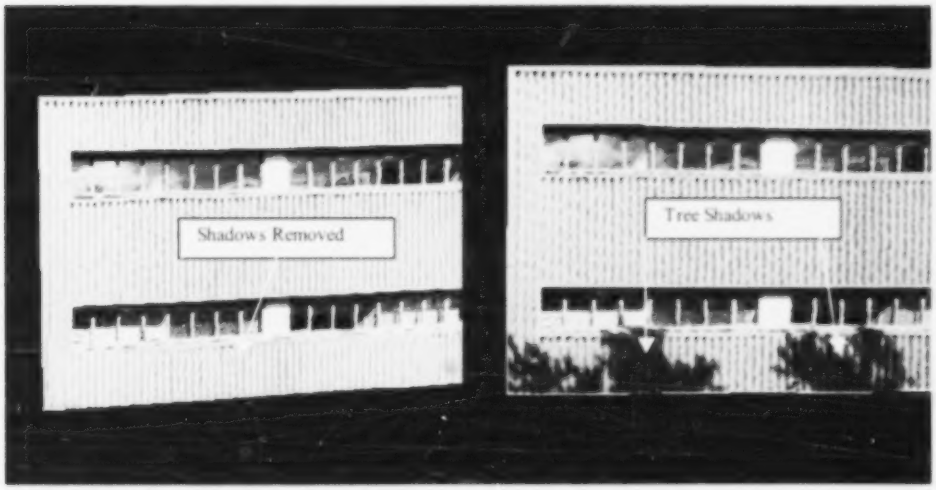

Figure 36. Refinement of Photo Texturing Using Brush Tools in Paint Shop Pro

[6] It was found that PM is well suited for photo texturing. PM provides automated selection of images from multiple sets based on pre-set criteria such as distance or angle of incidence, provides accurate feathering and warping of images to fit the models, and allows users to select preferred images for PT.

[7] Since solving points in PM already typically requires selection and marking of the building corners, PT is provided at minimal extra time cost, compared to traditional PT techniques, which require marking texture points separately, and in addition to the 3D modelling process.

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2.4 Use of Archived Image Data for Feature Extraction and Photo Texturing

2.4.1 Proof of Concept Using Griffon Pictures

[1] The PM package has tools available to extract and solve dimensions from images or photos, even when camera calibration isn't known. This feature enables archived images to be analyzed and even used to solve unknown points or dimensions.

[2] In the first call-up, a detailed model of a Griffon helicopter was produced from detailed laser scans data. To test the ability of PM to use archived images, and solve unknown (or inverse) uncalibrated cameras, digital images of the control panel, along with the laser scan data were used in PM to PT the front control panel.

[3] One archived image of the front control panel is shown in Figure 37. This image, along with a similar one was loaded into PM, in a new project, shown in Figure 38.

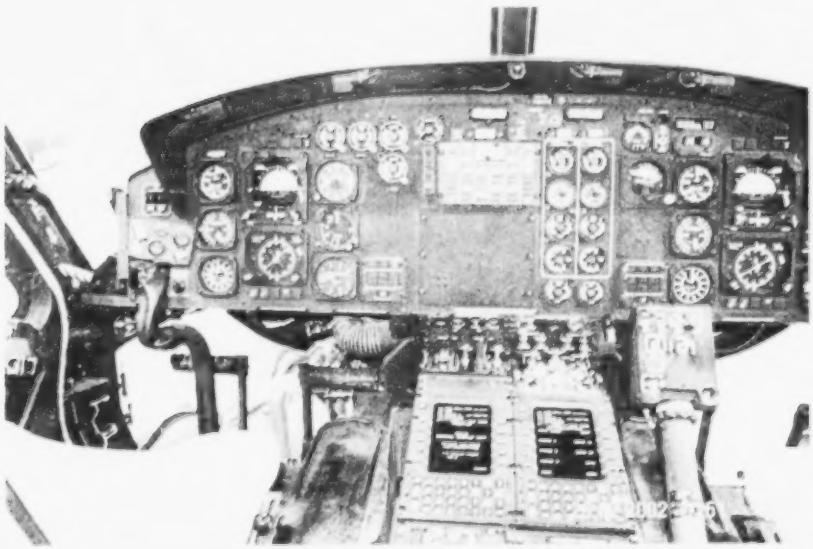

Figure 37. Digital Image of Griffon Helicopter Control Panels and Sticks

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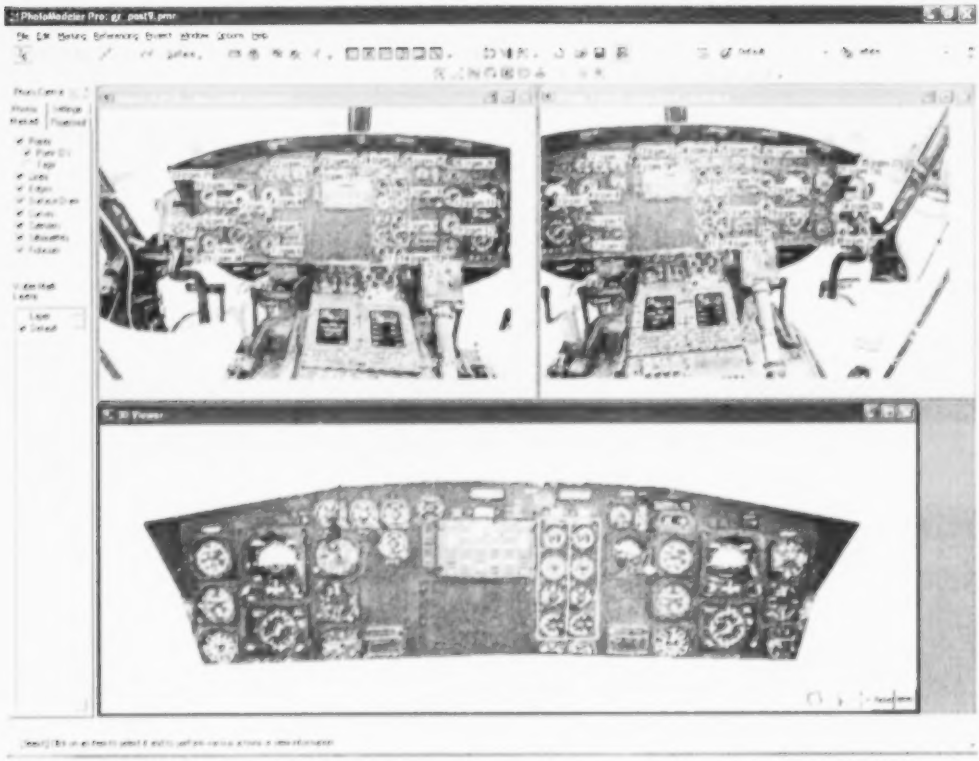

Figure 38. PhotoModeler Project for Griffon Panel Photo Texturing

2.4.2 Solution Method and Results

[1] The preferred method for solving an unknown, uncalibrated camera (inverse camera problem) is to use control points. Since we have detailed, dense polygon models of the front panel, numerous points were identified and exported from IMinspect, as shown in Figure 39. Many of the points are the centers of dials, or corners of bezels. These points are easily identifiable and marked/registered in the digital images.

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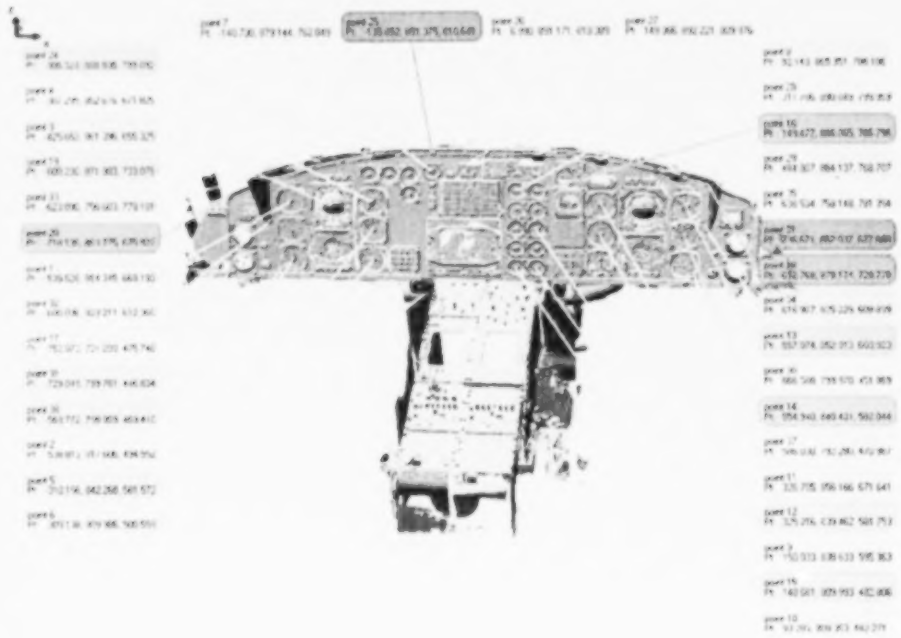

Figure 39. Locations of Control Points for Photo Texturing

2.4.3 Resulting Photo Textured Surfaces

[1] The control points shown in Figure 39 were imported into PM, marked on the two images, and used to solve the camera. In addition to the geometry of the control points, the images from the camera used contain EXIF information. EXIF is a manufacturer independent standard way of coding camera and photo specific information into image files, saving and archiving items such as film speed, shutter speed, aperture setting, focal length, date, time, etc. This permanent record of information coded into the image is read and decoded by PM to assist the solution. EXIF has only been in place for approximately two years, and is still not fully implemented, but already it provides many advantages for digital photogrammetry.

[2] Figure 40 and Figure 41 show the Griffon model without and with PT, respectively, as viewed in IMedit. Note the more realistic appearance of the panel in Figure 42. Also, a significant number of polygons may be removed from the front panel.

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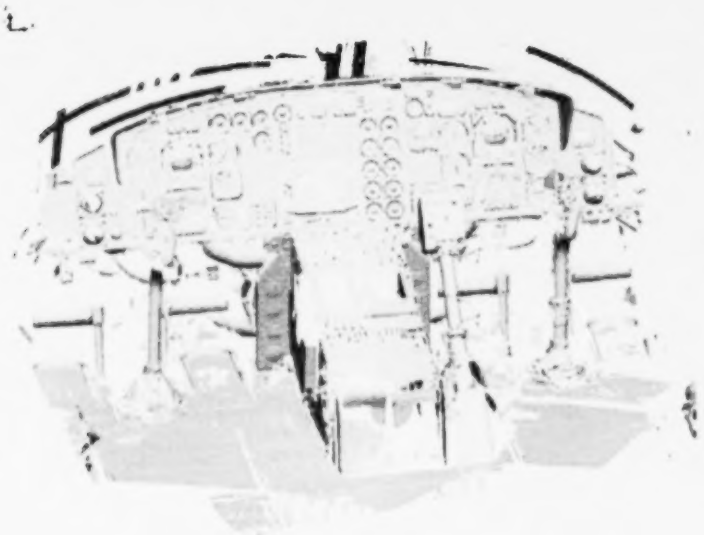

Figure 40. Non-Textured Polygon Model of Griffon Interior

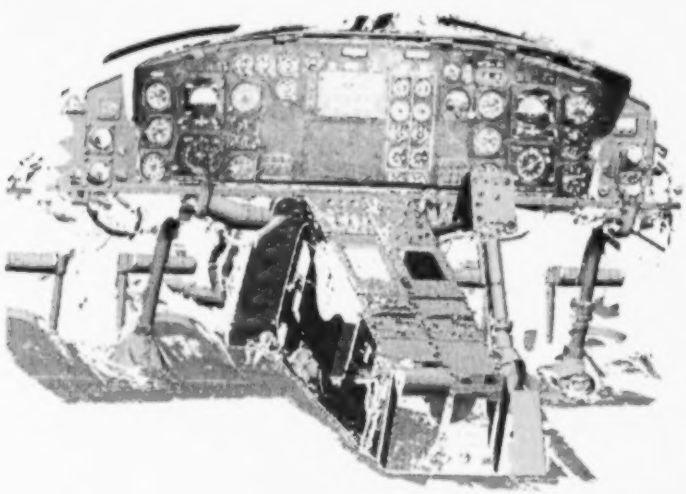

Figure 41. Polygon Model of Griffon Interior With Photo-Textured Front Instrument Panel

[3] Figure 42 shows the PT control model exported from PM, displayed in Rhino. Rhino has the ability to use PT polygon data, though not PT NURBS models. Other 3D graphics modelling packages such as Maya, 3D Studio Max, and Multigen Creator offer more advanced tools for PT model editing.

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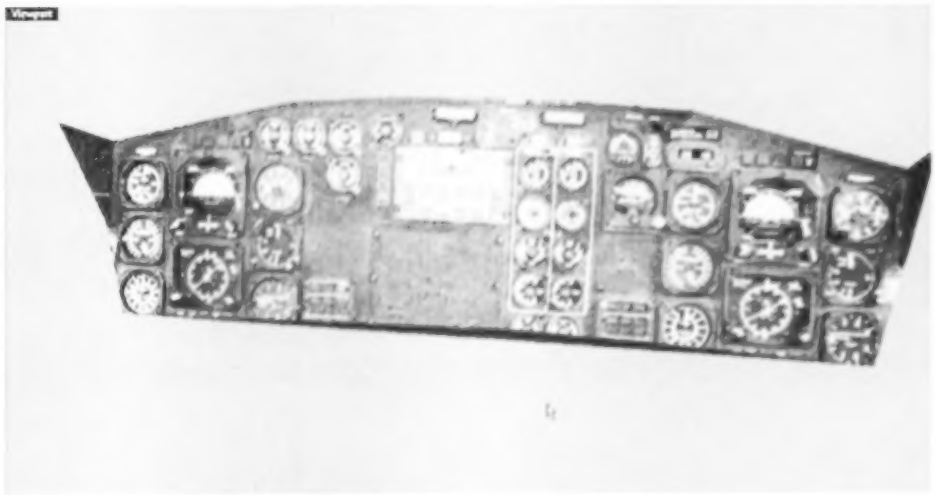

Figure 42. Photo Textured Control Panel Model In Rhino Software

2.5 Demonstration of Single-Photo Texturing Application

2.5.1 Overview: CF 18 Model Airplane

[1] One final PM example project was undertaken for this call-up, to demonstrate and evaluate PM to model and PT from a single image. Using a single image (for a small object) has important advantages, as there is no need to feather or match two images. This is especially important when shadows, or different lighting is noticeable among images.

[2] For this study, a small CF 18 scale model airplane was previously laser scanned by Shape Grabber, and Polygonized in Polyworks Immerge. The model was photographed with the Olympus 5050, and a new PM project created. Calibration information from the floor grid was used for this project, as the plane fit nicely in the volume of the floor grid, and high accuracy was not critical.

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2.5.2 Method and Results of Single Image Texturing Demonstration

[1] As in previous projects, control points were selected in IMinspect and exported to PM. These point locations are shown in Figure 43.

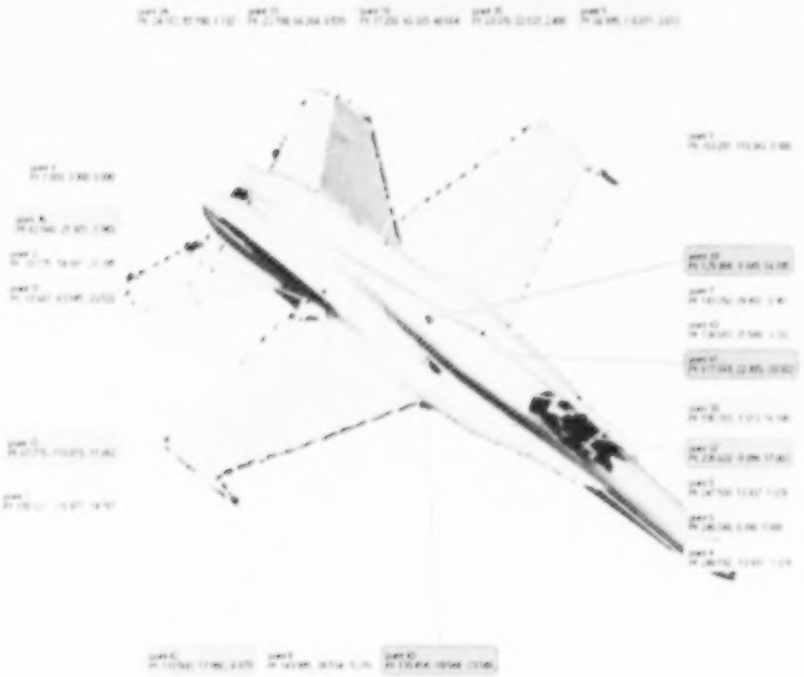

Figure 43. Location of Control Points in Laser Scan Polygon Model for Texturing CF 18 Model Plane

[2] A screen capture of the PM project is shown in Figure 44. The imported control points were located and marked in the image with PM.

[3] The surface draw feature of PM was used to draw and define surfaces (trim them in this case) describing the aircraft. This enabled a simple PT model to be created rapidly from the single image.

[4] Figure 45 shows the resulting texture map for the CF18. Due to time constraints, only the wings and fuselage were modelled. This test shows the capability to map textures to models, even without having stereo image coverage. However, new points and surfaces cannot be added to the model from the images, unless they lie on a surface defined by control points. This simple example shows the ability of PM to add PT to an existing model using a single digital image and control points.

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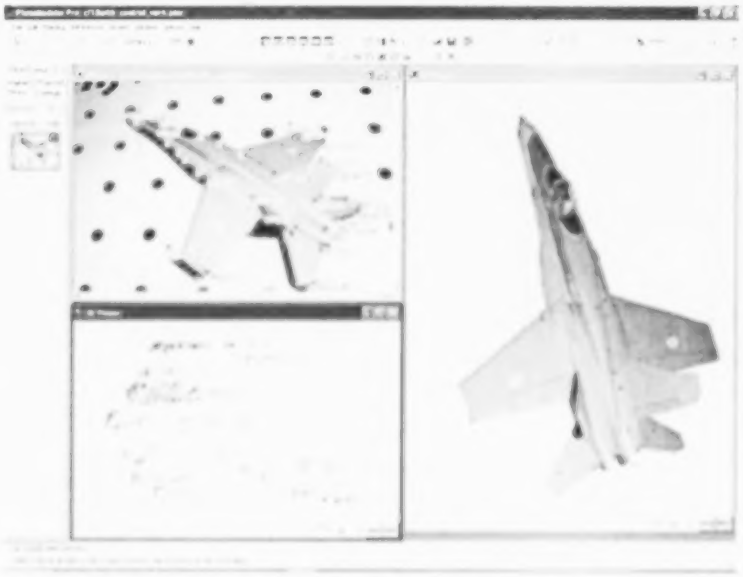

Figure 44. PhotoModeler Project for CF18 Single Photo Texturing

Figure 45. Photo-Texture Map for CF18 Model Aircraft

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3 CONCLUSIONS AND RECOMMENDATIONS

3.1 Comparison of Laser Scanning and Photogrammetry Methods

[1] Based on this study, the advantages and disadvantages of both laser scanning and photogrammetry compared to each other can be summarized, as shown in Table 1 and Table 2.

Table 1. Relative Advantages and Disadvantages of Laser Scanning

Advantages	Disadvantages
Excellent Global Scale Control	Longer Data Acquisition Time
Selectable Grid	Bulky Equipment/ Lack of Portability
Efficient Scan Registration	Requires defined, solid surface
Real-time 3D data Collection	Requires larger line of sight standoff (> 1.5 m)
More automated data acquisition	Minimal texture information captured (Vertex Color)
Single line of sight, no triangulation	More expensive sensors
	Results not as easy to interpret/visualize

Table 2. Relative Advantages and Disadvantages of Digital Photogrammetry

Advantages	Disadvantages
Shorter Acquisition Time	Longer post-processing time
Photo texturing possible	Need to have identifiable points
Portable	Not real-time 3D, post-processing required
Data easy to interpret/visualize	More labour intensive post-processing
Requires shorter line of sight standoff	Less automated acquisition capability
Less expensive sensors	Requires triangulation line of sight
Scalable level of details	Sensitive to Scale Errors

3.2 Integrated System Advantages and Characteristics

[1] This study proposed and demonstrated an approach to integrate laser scanning and photogrammetry data to use the advantages of both methods, and minimize the disadvantages.

[2] Conceptually, when using the integrated approach, the overall framework of an object can be primarily measured with a laser scanner, while digital photogrammetry is used to augment and backup the scanning. This provides efficient data acquisition and processing, while providing global scale control and archiving of information.

[3] Close range photogrammetry of a laser scanned object also provides redundancy, convenient visual archiving of information, and also enables texture mapping (especially for flat objects), and the ability to extract features and dimensions later.

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[4] Photogrammetry also enables close-range detail acquisition in areas where scanning is not feasible (such as in confined areas, or those with a short line-of-sight).

3.3 Proposed Use of Photogrammetry Compatible Images Instead of Digital Photography

[1] In previous laser scanning of large objects such as CF aircraft, the objects were extensively photographed with digital cameras. This study proposes that photogrammetry capable images be taken in the future, even if they aren't initially used for that purpose. This enables measurements to be taken from them in the future, should the need arise.

[2] For this purpose, the extra requirements of photogrammetry capable images instead of regular digital images are summarized below:

- Ensure stereo image coverage of objects (minimum two views separated by 40 degrees or more convergently), three views of all objects is preferred with 90 degree total coverage.
- Take overlapping images with at least six common points contained in adjacent images.
- Use calibrated cameras, or calibrate shortly after images are taken (as soon as possible).
- Take all images at same focal length, minimum or maximum zoom only, disable digital zoom.
- Ensure images have a scale reference – either add a scale bar/reference length or measure a distance, or ensure features with accurate laser scanning are imaged.
- Ensure uniquely identifiable points are present – either natural features (points, edges, corners), or add artificial targets.
- Photogrammetry requires special SW (PM), and expertise/training for post-processing.

3.4 Summary of Findings and Recommendations

[1] An integrated method for laser scanning and digital photogrammetry was successfully demonstrated using an Olympus 5050 camera, Cyrax laser scanner, PM software and calibration grid, Innovmetric's Polyworks software.

[2] Based on the research and testing of this call-up, the following findings and recommendations are suggested:

1. Shape Capture is not ideally suited for ship measurement applications as it is missing some desirable features such as NURBS modelling, import/exchange compatibility, and stand-alone calibration capability.
2. The Olympus 5050 digital camera is well suited to ship measurement applications.
3. PhotoModeler is well suited to ship measurement applications, and has features useful to efficiently augment laser scanning.
4. Global and local scale control are important in photogrammetry, so, we recommend adding a scale reference with photo compatible targets where possible, in addition to using laser scan control points.
5. Depending on the level of detail required and surface to be measured, the scanning grid point spacing may be increased from 0.020 m to 0.050 m without a major loss of accuracy in photo models.
6. Approximately 0.75 hours post processing per digital image is required for registration, matching, and processing using PM.

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7. Accuracy using photogrammetry without precise scale control (scale bar) or photo targets is 2-5 cm for large objects (side of building) using Cyrax laser scan for control points.

8. With precise scale bar and photo targets, less than cm accuracy is possible, within the volume of the scale reference and calibration grid.

9. Further calibration studies using an overhead projector instead of a slide projector are suggested.

10. Photo texturing works well for planar objects, especially when an object can be captured completely in one image.

11. PhotoModeler exports are compatible with Polyworks and Rhino, but there is some trouble with editing photo texture models with these programs. Other modelling SW for editing PT data is recommended such as 3D Studio Max/ Maya/ Multigen Creator SW.

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4 LIST OF ACRONYMS AND ABBREVIATIONS

Table 3 lists the acronyms and abbreviations used in this document.

Table 3. Acronyms and Abbreviations

Acronyms and Abbreviations	Explanation
3D	3-Dimensional
AC	Air Conditioner
CCD	Charge-Coupled Device
CF	Canadian Forces
cm	centimetre
DRDC-Toronto	Defence Research & Development Canada - Toronto
HW	Hardware
m	metre
mm	millimetre
NRC	National Research Council
NURBS	Non-Rational Uniform B-Spline
PM	PhotoModeler
PT	Photo-Textured
RMS	Root Mean Square
SC	Shape Capture
SLR	Single-Lens Reflex
SMART	Simulation and Modelling in Acquisition, Rehearsal and Training
SW	Software

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14. ABSTRACT

(U) The results of a technology demonstration study are presented for the Defence Research & Development Canada (DRDC) Toronto's Human Modelling Group. This report describes a method and system for integrating laser scanner and digital photogrammetry data. It proposes and demonstrates an integrated solution using a Cyrax laser scanner, Olympus 5050 Digital Camera, PhotoModeler Software, and Innovmetric Polyworks software.
The proposed system enables digital photogrammetry to be used to: augment and back up laser scanning coverage, add detailed local coverage to a larger global model, provide semi-automated photo texturing of three-dimensional (3D) models (reducing polygon counts in some cases), reduce the required laser scanning grid size for some objects, and extract features or dimensions from previously archived images.
This study found that cm level accuracy can be obtained from photogrammetry of large objects (as shown in the pilot project by measuring two sides of the DRDC Toronto building). Recommendations are made for implementing this technology, especially by replacing existing digital photography of scanned objects by photogrammetry compatible imaging.
The combined system offers numerous advantages over either technique separately including improved data collection efficiency, improved visualization, and the ability to extract dimensions from digital images.

(U) Les résultats d'une étude de démonstration de technologie sont présentés pour le groupe de modélisation humaine de Recherche et Développement pour la défense Canada (RDDC) Toronto. Le présent rapport décrit une méthode et un système d'intégration de données obtenues par balayage laser et photogrammétrie numérique. Il propose une solution intégrée au moyen d'un lecteur laser Cyrax, d'un appareil photo numérique Olympus 5050, du logiciel PhotoModeler et du logiciel PolyWorks d'InnovMetric, solution dont la démonstration est faite.
Le système proposé permet d'utiliser la photogrammétrie numérique pour augmenter la couverture du balayage laser et lui servir de relève, ajouter une couverture locale détaillée jusqu'à concurrence d'un modèle global de taille plus grande, assurer la texturation semi-automatique de modèles tridimensionnels (3D) (en réduisant le nombre de polygones dans certains cas), réduire la taille de la grille de balayage laser nécessaire dans le cas de certains objets et extraire des caractéristiques ou des dimensions d'images archivées.
La présente étude montre qu'il est possible d'obtenir une précision au niveau du centimètre à partir des données de photogrammétrie d'objets de grande taille (comme l'illustre le projet-pilote par la mesure de deux côtés de l'immeuble de RDDC Toronto). Des recommandations sont formulées pour la mise en œuvre de cette technologie, en particulier par le remplacement de photographies numériques d'objets balayés par des images compatibles de photogrammétrie.
Le système combiné offre de nombreux avantages par rapport à chacune des techniques prises séparément, dont la collecte plus efficace de données, une meilleure visualisation et la capacité d'extraire les dimensions d'images numériques.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) 3D modelling, laser scanning, photogrammetry